EXPERT INSIGHT FOR RAN SUBSCRIBERS

CBRS Spectrum Valuation:

How much would a PAL license cost (county-by-county)?

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Introduction

After many years of coordination with federal agencies, product development, and testing, a path to CBRS commercialization is becoming a bit more clear. Several SAS and ESC vendors have wrapped up necessary NTIA testing and await FCC approval.[1] As the market anticipates commercial launch in the second half of this year, suppliers have begun to announce infrastructure, device, and solution offerings with market pricings. Google, for instance, announced its SAS pricing for fixed wireless application, and others are beginning to announce product and solution pricings for different applications.

With increasing clarity on costs of CBSD radio infrastructure, SAS/ESC, EPC Core, devices, etc., operators can begin to validate their business cases across the different use cases whether it's fixed wireless access, private LTE enterprise services, or mobility. Although the initial CBRS/OnGo commercialization will start off with GAA, many service providers will contemplate securing PAL licenses to ensure "guaranteed" access to the CBRS spectrum. Depending on how much the CBRS spectrum may cost, for PAL licenses, some business cases may or may not work out. Spectrum cost will certainly be a part of an operators' CAPEX equation and will determine the operators' CBRS investment decisions.

This *EXP Insight* paper highlights key factors that influence spectrum value – largely based on supply and demand dynamics. Using this framework as a first-level "filter" to understand qualitative assessment of potential value for the CBRS spectrum against the various business use cases, the paper proposes quantitative framework to come up with PAL spectrum cost estimates – looking at demand for PAL licenses by county (i.e., the license geographic area) for the three primary use cases as noted above.

Spectrum Valuation Framework

Valuing spectrum is a very difficult task. It depends on so many factors that are, honestly, almost impossible to quantify and to get them right. A set of rationales that one player uses to come up with a certain valuation may be different for another player. For instance, a mobile operator who doesn't have an available spectrum to increase network capacity may be more willing to pay higher price versus another player with an ample supply of spectrum. Or, the player may simply decide to go with network densification rather than adding more spectrum carriers to increase capacity. Separately, a player with multiple "supply-side" options such as additional spectrum or

[1] https://www.ntia.gov/blog/2019/spectrum-sharing-model-gaining-ground

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technology alternatives may be more inclined to wait for the right (lower) price for an upcoming spectrum auction. Like most things, valuation is in the eye of the beholder. For instance, smaller wireless ISPs serving rural markets with fixed wireless access (FWA) service would be less inclined to spend the big bucks for spectrum as compared to major mobile operators who are used to investing billions of dollars in spectrum auctions.

While we acknowledge that valuing spectrum is more of an art than science, it is helpful to set up a logical framework to assess valuation, at least qualitatively. Below is a list of potential factors that we believe a rational player would consider:

- Quality of spectrum (bandwidth, frequency band, license term, and duration)
- Added value from deployment (new business or meeting existing traffic demand)
- Strategic asset (competitive barrier to entry, resale value)
- Supply-side alternatives (spectrum pipeline, availability of technology substitute)
- Timing and competitive landscape
- Regulatory risk (uncertainty, favorability of rules)
- Ecosystem maturity (availability of product solutions)

Quality of CBRS Spectrum

Fundamentally, the sharing aspect of the CBRS spectrum (3550-3700 MHz) makes it less desirable compared to traditional licensed spectrum bands (e.g., 600MHz, AWS, etc.). However, the 70MHz of total PAL license spectrum[2], and up to 40MHz per operator is a welcome relief for some operators who may be looking to add comparatively inexpensive spectrum for different use cases (e.g., mobility, fixed wireless, private LTE, etc.). Moreover, the PAL licensing terms based on county-size areas and 10-year term make the CBRS PAL licenses a bit more attractive for larger players to invest. While the rulemaking and timing of the adjacent C-band (3700-4200 MHz) are unknown at this time, there is a possibility that the CBRS spectrum can be complementary to this strategically important C-band for mobile use. This may subsequently make the CBRS spectrum more valuable for mobile, and possibly cable, operators.

While there are positive and negative aspects to the CBRS PAL spectrum licensing, we believe the quality of CBRS PAL licenses is slightly net positive when evaluated cumulatively across the different use cases including private LTE, FWA, and mobility.

[2] Seven 10-MHz channels will be licensed as PAL licenses per (county) market

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Added Value from Deployment

The value of spectrum is fundamentally tied to how much value that an operator can derive from deploying that spectrum in a network. For operators running mobile networks, the need for more spectrum is almost a never-ending story as traffic demand continues to grow each year. While there may be significant variability in the level of demand for spectrum across different operators – dependent on market share, device penetration, service pricing, Wi-Fi offload, etc. – the mobile operators are always seeking more spectrum. A desire for more spectrum, hence higher value, is also true for other operators as well. While enterprising wireless ISPs (WISPs) use a variety of licensed and unlicensed spectrum (e.g., 5GHz, 2.5GHz, 3.65 GHz, etc.) for FWA services, their need for more spectrum, preferably in the lower bands, is another never-ending saga as they continuously expand network capacity and offer higher-speed broadband services to their subscribers.

For the Private LTE use case, the value of new "clean" spectrum in the CBRS band offers a new business opportunity for neutral host providers or enterprises to run higher grade services that provide more deterministic bandwidth for critical applications such as retail POS, video surveillance, etc. While business cases related to new Private LTE applications need to be proven out in the marketplace, there is a growing awareness among leading enterprises that Private LTE networks can offer higher-quality wireless network capabilities that may prove essential for certain enterprise applications.

Strategic Asset?

Licensed spectrum has been a key strategic asset for mobile operators for decades. Verizon and AT&T, for instance, have enjoyed competitive advantages over T-Mobile and Sprint for decades with their low-band spectrum holdings resulting in broader mobile network coverages. Since the licensed spectrum is finite, there is upside in keeping licensed spectrum out of the hands of competitors, whether or not the spectrum is deployed. This "foreclosure" value of spectrum is less so with the CBRS spectrum since it is shared with federal and other incumbents at the moment. Moreover, the performance requirement[3] and opportunistic GAA use[4] provisions make warehousing of spectrum less likely. While the CBRS spectrum probably does not provide a barrier to

[3] 50% population coverage is required for mobile (point-to-multipoint) use and a minimum number of point-to-point links equal to the population of the license area divided by 33.5K for the fixed wireless use case, at the end of a 10-year license term

[4] GAA use is allowed for unused PAL spectrum

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entry for competitors, its resale value remains intact, especially so, since the partitioning and disaggregation provisions[5] in the 3.5 GHz band will likely foster an active secondary market for the spectrum. A licensee can resell the PAL spectrum in smaller chunks in the secondary market if it decides not to deploy the spectrum directly.

Capacity Supply Alternatives

The value of the CBRS PAL spectrum needs to be evaluated in the context of other supply-side alternatives. If there are many alternatives available, market participants may simply choose to forgo a spectrum auction. In wireless, operators have three levers to increase network capacity: 1) spectrum; 2) network densification; and 3) spectral efficiency through technology advancements. For mobility use case, the value of CBRS spectrum may not be as high given that the spectrum pipeline looks pretty robust with an abundance of the millimeter wave (24, 28, 39, 37 GHz, etc.) spectrum auctions taking place now. Moreover, the C-band spectrum will likely come online in the next few years – either through private sale transactions or FCC rulemaking. Alternatively, the mobile operators can refarm their sub-3GHz bands for 5G to gain additional spectral efficiency. For cable operators, the CBRS PAL licenses may offer inexpensive "mid-band" spectrum for their small cell offload strategy to aid in their MVNO businesses.

For certain Private LTE use cases requiring a wide-area coverage, CBRS PAL spectrum becomes valuable since it offers "guaranteed" spectrum use for enterprise applications that require carrier-grade quality of service. For FWA and mobility use cases, other spectrum (e.g., 2.5 GHz, 5GHz unlicensed) and technology options (e.g., Wi-Fi and WiMax) are available to serve those markets. Depending on the specific use case, the supply-side alternatives can be wide-ranging across both spectrum and technology planes.

Timing and Competitive Landscape

Spectrum valuation can also depend on market competition and timing. If a player believes that there are other suitable spectrum coming online through auctions or private sales in the secondary market, for example, the player may be less anxious to bid in the upcoming CBRS PAL auction. On the other hand, if the prospect to secure additional spectrum is dim, and market competition heats up, the player may be inclined

[5] The revised NPRM allows partitioning and disaggregation of PALs in secondary market transactions. Through secondary market transactions, licensees can decide the correct size of licenses on a market-specific and needs-based basis.

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to bid more aggressively – thus influencing the price higher. On the other hand, for private LTE indoor use case, PAL prioritization may not be that important since enterprises can potentially manage the use of wider CBRS spectrum range through a careful RF planning.[6] Similarly, for the mobile use case, operators have other means to expand network capacity – e.g., spectrum refarming, network densification, or millimeter wave small cells. Hence, the value of CBRS PAL for the mobile operators is not essential. It is nice to have the priority access to the CBRS "mid-band" spectrum but is not critical.

On the flip side, the CBRS PAL may be most valuable for WISPs who need access to more spectrum to cover wider areas to enable higher in-home broadband services. With rural broadband gaining more mindshare among politicians these days and additional government funding coming down the pipeline (e.g., $20B Rural Digital Opportunity Fund[7]), the timing may be right, now, to secure CBRS spectrum to broaden FWA footprint in more rural areas where broadband services are still lacking.

Regulatory Risk

The final CBRS ruling that settled on PAL licenses based on county-size geographic area and 10-year renewable terms have generally increased the value of CBRS PAL licenses (as compared to the original terms based on census tract areas and 3-year term licenses). The final CBRS rulings favor the larger players such as mobile and cable operators as the revised terms make the PAL licenses large enough for them to invest. Meanwhile, the compromised terms do not reduce the value of CBRS PAL for smaller WISP and private LTE players completely as the performance requirements, the opportunistic use of GAA for unused PAL spectrum, and the partitioning and disaggregation of CBRS spectrum will likely foster active secondary markets. Hence, the regulatory risks for the CBRS spectrum are minimal at this point and generally enhances the value of PAL licenses overall.

Ecosystem Maturity

The maturing CBRS ecosystem – represented by over 120 CBRS Alliance members – ranging from major mobile and cable operators, telecom infrastructure vendors, small cell specialists, device manufacturers, and system integrators, further enhances the

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[6] If an enterprise makes sure indoor RF doesn't sip outside a building, it can theoretically use wider CBRS spectrum bands under GAA

[7] FCC public notice on $20B Rural Digital Opportunity Fund, April 30, 2019.

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value of the CBRS spectrum as one can expect to find robust supplier ecosystem around this band. With the CBRS Alliance committing to a 5G evolutionary path, the CBRS spectrum is generally viewed as a “mainstream” spectrum band at this point – though its shared spectrum regime deviates from the general 5G mid-band spectrum allocations around the world.

In summary, the qualitative assessment of the factors that influence spectrum valuation shows that the CBRS spectrum is generally valuable for the three primary use cases for the initial CBRS commercialization, i.e., Private LTE, Fixed Wireless Access, and Mobility.

Spectrum Valuation Framework	Private LTE	Fixed Wireless	Mobility
Quality of CBRS spectrum			
Bandwidth	↑	↑	↔
Frequency band (complementary?)	↔	↔	↑
Transmission power (coverage)	↑	↑	↓
Licensing area (parcel size)	↓	↓	↔
Added Value from Deployment	↔	↑	↑
Strategic Asset			
Value as barrier to entry	↔	↔	↔
Resale value	↑	↑	↑
Capacity Supply Alternatives			
Spectrum pipeline	↑	↔	↓
Technology and network substitutes	↔	↓	↔
Timing and Market Competition	↔	↑	↔
Regulatory Risk	↔	↔	↑
Ecosystem Maturity	↑	↑	↑

Source: Mobile Experts

Figure 1. Factors influencing Spectrum Value/Price

Methodology to Estimate CBRS Spectrum Value

While we acknowledge that quantifying spectrum valuation is an error-prone process with several assumptions that are hard to measure or validate, we have used the following methodology to estimate CBRS spectrum cost.

1. We used the Clearwire spectrum asset sale in 2012 as a baseline reference for the average $ per MHz-Pop figure for the 3.5 GHz CBRS band. Our rationale for choosing this particular private transaction as a baseline figure is simply that the 2.5GHz

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spectrum asset involved in the Clearwire acquisition is simply close to the 3.5GHz CBRS band. Our rationale is that the 3.5 GHz CBRS spectrum would have inherently similar value based on similar RF characteristics (although sharing and transmission power limits will likely diminish the value of CBRS spectrum). The spectrum asset sale as a part of the Softbank/Sprint acquisition of Clearwire valued the 2.5GHz spectrum at $0.26 per MHz-Pop.[8]

2. We applied a fraction of this Clearwire baseline figure to derive a CBRS PAL $/MHz-Pop baseline. Since CBRS PAL has less desirable characteristics (i.e., smaller parcel size, lower transmission power limits, sharing, etc.), we have assumed that CBRS PAL license should cost a fraction of the Clearwire spectrum. Here, we applied a 1/10th discount.
3. We then applied proportional premium or discounts to average $ per MHz-Pop from the AWS-3 auction to the average CBRS $/MHz-Pop figures from #2 above on a county-by-county basis. It should be noted that AWS-3 auction was based on much larger Cellular Market Area (CMA) size. We manually matched County to CMA for the top 100 or so counties. For less-populated counties, we have applied similar discounts to average $/MHz-Pop figure from AWS-3 results based on CMA to counties.
4. We then designated whether major mobile and cable operators (for mobility use case), neutral host providers (for Private LTE use case), and WISPs (for FWA use case) would likely bid for PAL licenses in a given county.
    a. We assumed that three major mobile operators would likely bid for PAL in top 400 or so counties with high population density. These ~400 populated counties constitute about 200M population count, out of the 310M population as reported in 2010 Census. We assumed that the mobile operators have sufficient network capacity with the licensed sub-3GHz spectrum and would be less inclined to bid for PAL spectrum in the remaining “rural” counties.
    b. We assumed that one cable operator would likely bid for PAL in all counties. Since cable operators generally don’t overlap geographically, we assumed that cable operator bid for PAL would mainly be against mobile operators. In other words, Charter and Comcast would only bid for PAL licenses in counties where they serve. There may be a few counties where Charter and Comcast may decide to bid for PAL (e.g., in New York metro region), but we expect this type of overlap will be minimal.

[8] Forbes, “Sprint eyes aggressive growth with Softbank backing and Clearwire spectrum,” July 12, 2013.

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c. For Private LTE use cases, we assumed that neutral host providers would target top markets with lots of businesses. We have selectively chosen top 150 counties with at least 10,000 "private non-farm establishments" each. These ~150 counties cumulatively contain 3.8M businesses (out of 7.1M total according to the 2009 Census).

d. For the FWA use case, we assumed that WISPs would selectively target counties with household density between 100 and 500 households per square mile. Heavily populated counties with urban metro markets are assumed to addressed by cable and fiber providers. Similarly, we assumed that very rural markets with less than 100 households per square mile are assumed to be too sparse for WISPs to target. In reality, WISPs may selectively target population centers within "rural" counties with less than 100 households per square mile for example. Cumulatively, the targeted market across 330 counties contain over 40M households (out of 117M total according to the 2010 Census).

We cannot overemphasize that the CBRS spectrum cost estimates reported in this paper are *estimates*! The spectrum cost estimates noted in this paper should be used as a guideline – not as exact values that players will pay. Depending on potential participants in the auction bidding process, their metric for valuations may differ completely from our framework in Figure 1, or that their assessment of absolute $ figures may differ widely from our estimates.

Demands for the CBRS Spectrum

A key aspect of estimating CBRS PAL spectrum cost is to identify demands for the spectrum for new business opportunities or added value that the spectrum can bring to existing businesses. We have identified three broad categories of use cases to identify potential market participants and how much they may bid for PAL licenses. The three use cases are: 1) private LTE; 2) fixed wireless access; and, 3) mobility.

Private LTE Use Case – Target Markets and Enterprise and Neutral Host Bidders

Certain private LTE use cases requiring high-quality bandwidth delivery may seek CBRS PAL spectrum to attain more "guaranteed" access to the CBRS spectrum. According to the US Census, over 50% of private non-farm business establishments are located in the top 150 counties (out of roughly 3200 counties in the USA). We believe these top 150 or so counties as shown in Figure 2 below represent the most desirable markets for neutral host providers or large enterprises seeking to enhance "high quality" private LTE

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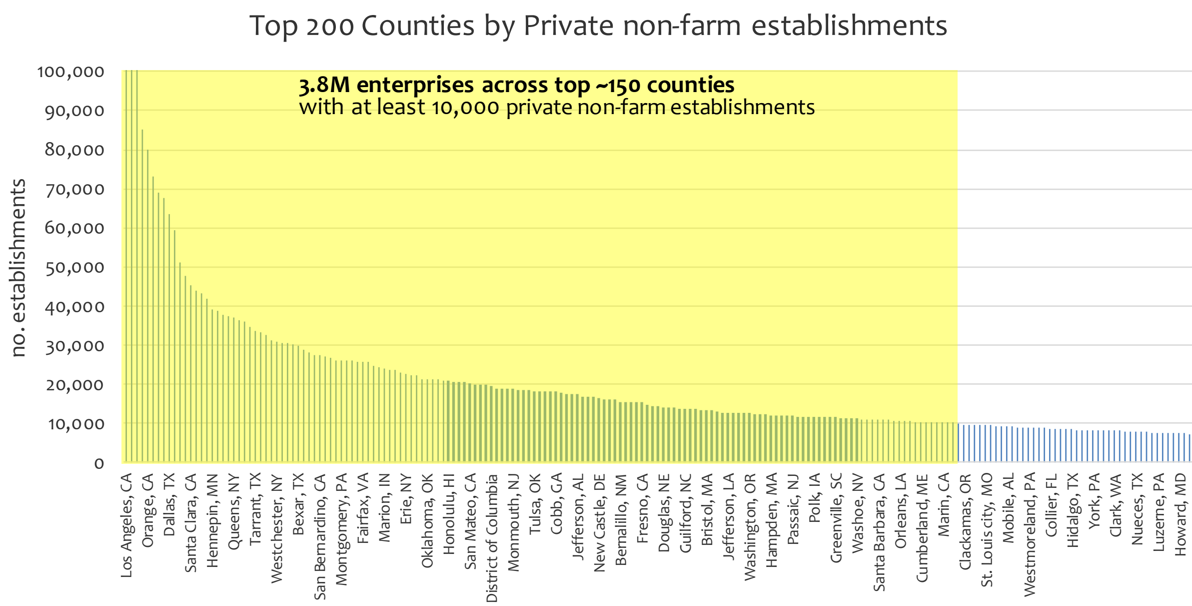
services through possibly obtaining PAL licenses. While many indoor services can potentially operate under GAA, we believe certain outdoor venue private LTE applications (e.g., golf courses, outdoor stadiums, etc.) may be better off with PAL licenses to ensure guaranteed access to the spectrum across the larger geographic footprint.



Sources: Mobile Experts

Notes: 1. The number of private non-farm establishments ranges from over 220K in Los Angeles County to less than 10 in Loving County, TX.
2. The y-axis range for the top 3 counties with over 100K establishments is purposefully truncated.

Figure 2: Target markets for Private LTE enterprise use case

FWA Use case - Target Markets and Rural Operator and WISP Bidders

Fixed wireless access (FWA) provides an economical substitute for in-home broadband service in sparsely populated rural markets where wireline infrastructure is too costly to deploy. While certain edges of suburban markets are also suitable for FWA, it is primarily attractive in unserved or underserved rural markets. Heavily populated metro and suburban markets are well served through fiber and cable broadband services, so it makes little sense to overbuild in those markets. For the purpose of estimating the CBRS spectrum value for the FWA use case, we have identified those counties that have a household density between 100 and 500 households per square mile. In reality, we believe there are population centers within "rural" counties outside of our selection

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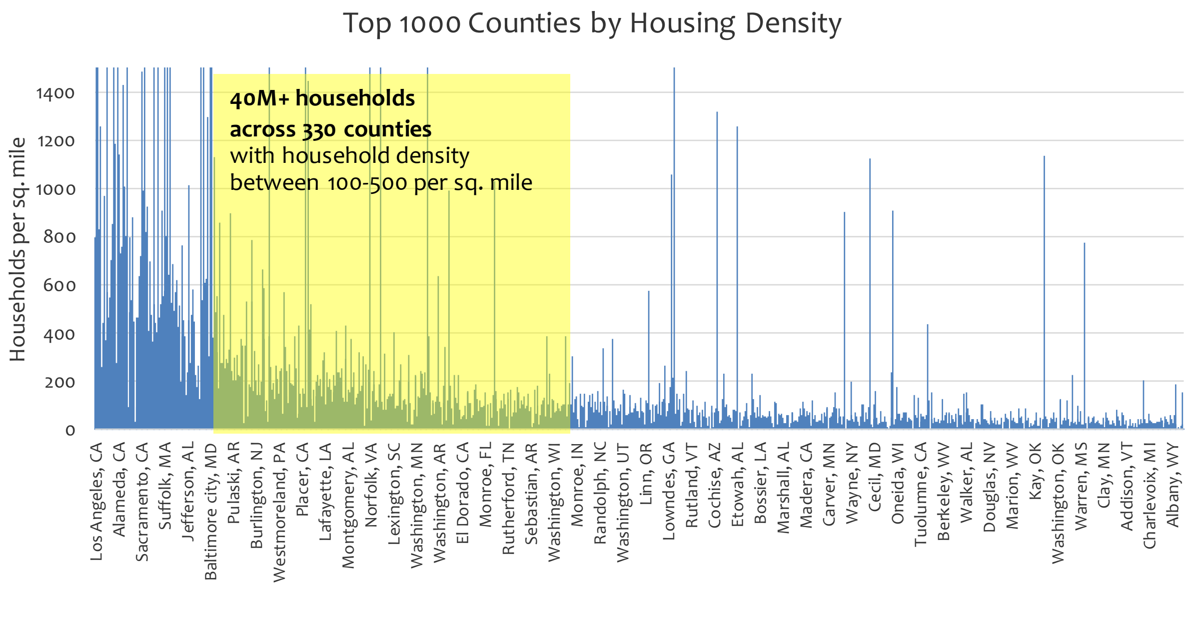
window (between 100 and 500 households per square mile) that are attractive for the FWA in-home broadband delivery. In the same token, we believe there are population centers within our selected counties that are well served by cable or telco broadband providers and FWA may not be competitive in those markets.



Sources: Mobile Experts

Notes: 1. The household density ranges from over 33K in NY County to less than 1 per sq. mile in Denali County, AK.
2. The y-axis ranges for the top 25 counties with over 1500 households per sq.mile is purposefully truncated.

Figure 3: Target markets for Fixed Wireless Access by WISPs

While we have identified the selected 300+ counties sandwiched between "urban" counties with dense population centers and "rural" counties with sparse population density (highlighted in yellow in the figure above), there are over 40M households across the 2700 "rural" counties. For some enterprise WISPs or rural operators, there may be concentrated population centers within those rural counties to make PAL spectrum investment to more guaranteed access to the spectrum. Moreover, those markets will likely be fairly inexpensive.

Mobility Use case - Target Markets and Mobile and Cable Operator Bidders

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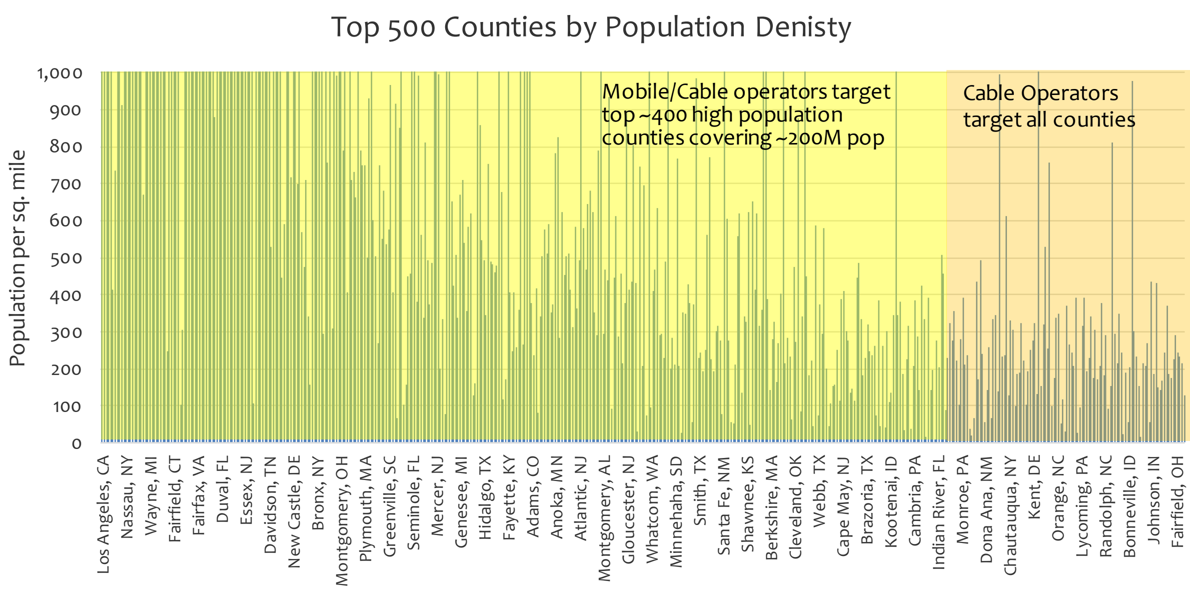
The mobility use case remains a key driver for spectrum, and the largest bidders for the CBRS PAL spectrum will likely come from this segment. While the spectrum pipeline in the USA remains quite robust, the need for the mid-band spectrum remains high. Outside of Sprint with its hefty 2.5 GHz spectrum holding, we expect the remaining three major mobile operators will bid for the PAL licenses to strengthen access to this mid-band CBRS spectrum in a more guaranteed way. In addition to the mobile operators, we expect major cable operators will also contend for the PAL licenses to help facilitate their facilities-based mobile networks.

We estimate that the mobile operators' demand for the CBRS PAL spectrum will be limited to about top 400 counties (~13% of the total number of counties) with at least 300 Pop per square mile. While this selection criteria is somewhat arbitrary, we believe mobile operators have alternatives, such as sub-3GHz spectrum re-farming and dynamic spectrum sharing technology, that allows the mobile operators to more efficiently utilize their licensed spectrum holdings. Unlike mobile operators, the cable operators may seek to secure PAL licenses in all counties to make sure that they have access to the mid-band CBRS spectrum as a potential baseline layer of their LTE mobile network.



Sources: Mobile Experts

Notes: 1. The population density ranges from ~70K pop/sq.mile in New York, NY to less than 0.1 in Loving, TX.
2. The y-axis range for about top 150 counties is truncated to showcase the ranges of less dense counties.

Figure 4: Target markets for the Mobility use case

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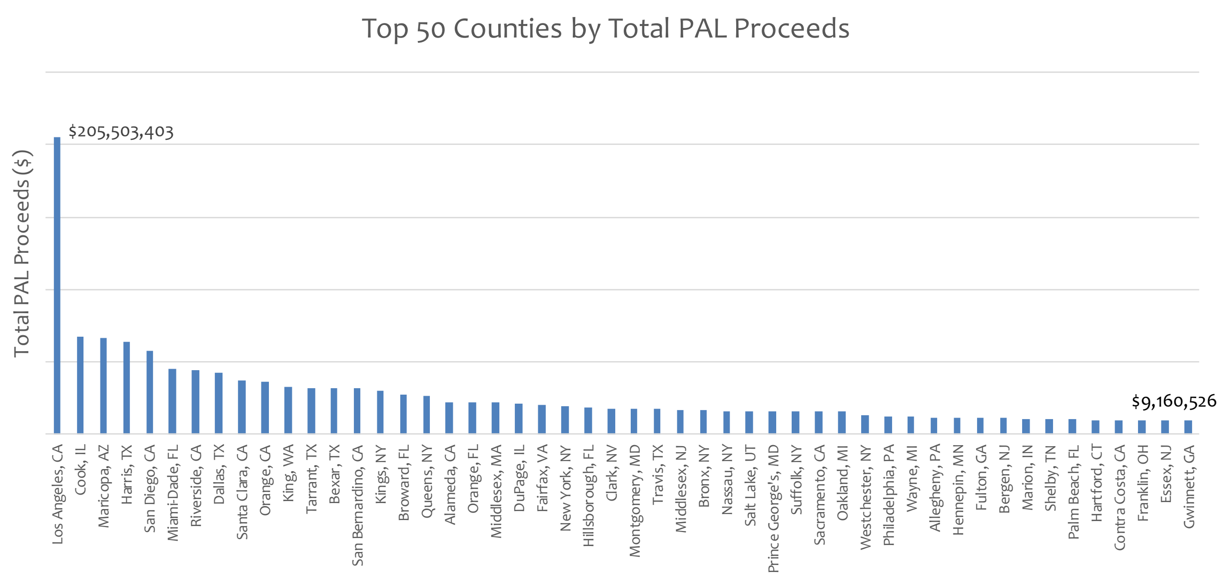
A combined demand from the mobile and cable operators for the mobile use case will likely drive the bulk of the PAL spectrum licenses across most populated counties.

CBRS PAL Spectrum Estimates

As outlined in the *Methodology* section, we have used the past market transaction and spectrum auction results to come up with market-by-market spectrum pricing. We then apply the demand criteria to further estimate the CBRS PAL spectrum pricing on a $ per MHz-Pop basis. The total PAL proceeds per county are calculated based on the assumption that all seven 10-MHz channels for PAL that will be auctioned off.

Top Markets by Total PAL Proceeds

The total PAL proceeds are estimated at $2.2B from seven 10MHz channels or PAL licenses. The top 50 most expensive counties are estimated to hold over 60% of total PAL proceeds – equivalent to over $1,350M. The Los Angeles County with its large geographic area and high population count is expected to be the most expensive market with over $200M of total proceed for seven PAL licenses. For the top 50 counties, a PAL license cost can range from just under $30M in Los Angeles County, CA to $1.3M in Gwinnett County, GA which includes the Atlanta metro suburbs.



Source: Mobile Experts

Note: The PAL auction proceeds for each market (county) assumes seven 10MHz channels

Figure 5: Most expensive top 50 counties make up over 60% of total PAL proceeds

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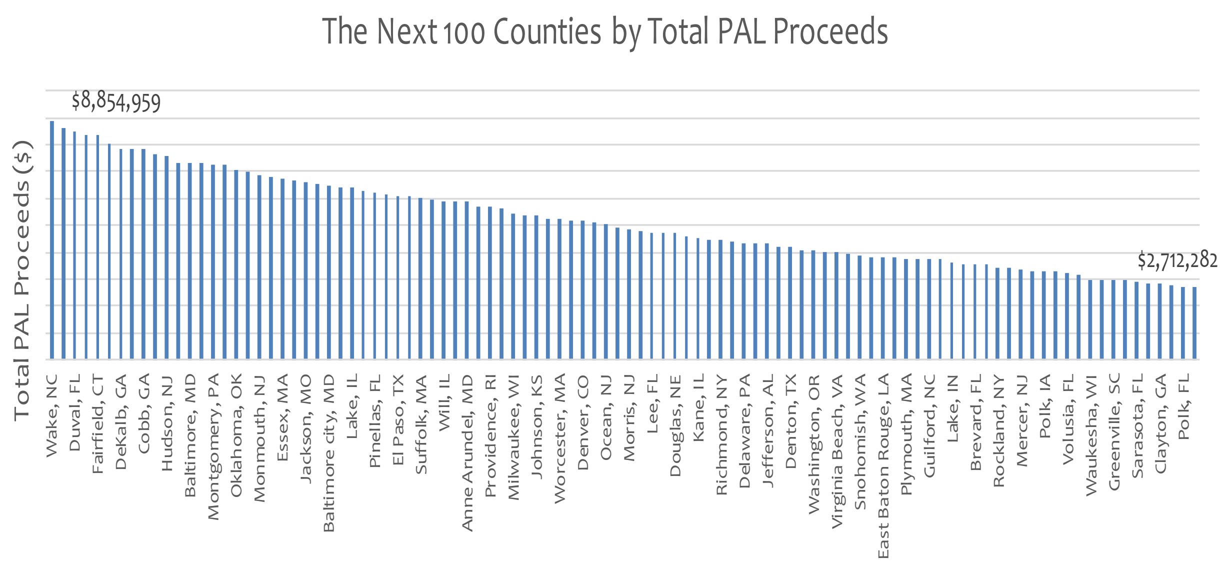
The next top 100 expensive counties are estimated to hold about 25% of total PAL proceeds – equivalent to over $510M, and an average PAL license cost ranges from $1.2M in St. Louis, MO to just under $400K in Genesee, MI, adjacent to the Detroit metro market.



Sources: Mobile Experts

Note: The PAL auction proceeds for each market (county) assumes seven 10MHz channels

Figure 6: The next 100 expensive counties constitute ~25% of total PAL proceeds

The remaining 3000 or so counties hold the remaining 15% of total proceeds – equivalent to about $330M. The average single PAL license can range from less than $380K in Clark, WA to about $100 in very rural counties like Lewis, ID.

Top Markets by $ per MHz-Pop

On a $ per MHz-Pop basis, the PAL price estimates range from about $0.30 in top counties of major metro markets likes Chicago, NY, and Los Angeles to about $0.003 in very rural counties. Based on our key assumption that major mobile operators would target the top 400 counties with the highest population density, the PAL estimates in those top 400 counties ranges from $0.30 to $0.06 per MHz-Pop. Just beyond that top segment of the market, the PAL estimate quickly drops to less than $0.02 per MHz-Pop.

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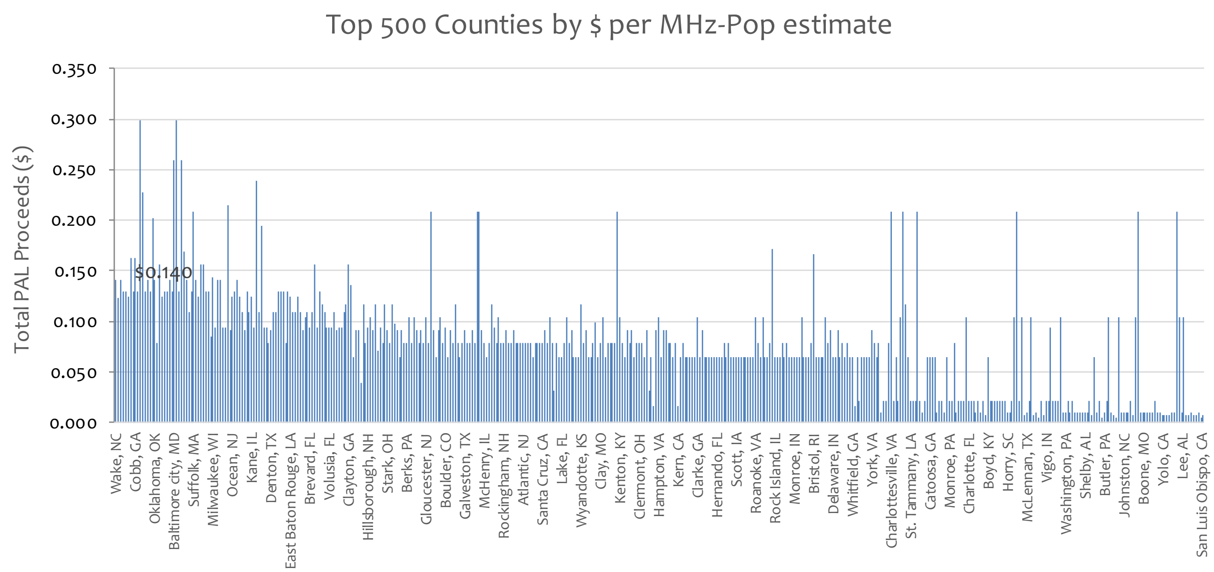

Sources: Mobile Experts

Figure 7: CBRS PAL estimates of top 500 counties by $ per MHz-Pop

Based on our methodology, a single 10MHz PAL license in non-tier 1 counties (beyond the top 400 counties) costs less than $50K.

Conclusions

As CBRS nears commercialization, different stakeholders looking to harness the 150 MHz of the 3.5GHz spectrum are undoubtedly assessing their PAL strategies – i.e., whether to bid for PAL licenses and if so, how much. A qualitative assessment of the CBRS spectrum valuation for the three primary use cases, and likely players behind those services -- namely neutral host providers or enterprises for private LTE, WISPs and rural operators for fixed wireless access, and major mobile and cable operators for mobility – highlights that the CBRS spectrum is generally valuable and that PAL licenses will likely be sought out by many potential bidders.

Based on our quantitative analysis of the supply (i.e., seven 10MHz PAL licenses per county) and demand (i.e., potential bidders ranging from mobile and cable operators, WISPs and enterprises), the total PAL proceed is estimated to be around $2.2B, and an average PAL license is estimated to be around $100K. The top 200 most expensive markets (see Appendix F), out of over 3000 counties in the USA, constitute about 90% of the total PAL proceed.

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On a per MHz-Pop basis, the average PAL license is estimated to be $0.102 per MHz-Pop. The most expensive market is Los Angeles County with its vast geographic footprint and high population count. A PAL license in Los Angeles is estimated to cost just under $30M, and the seven PAL licenses there may yield around $200M in total proceeds. Most expensive markets on a per MHz-Pop basis will include counties surrounding key metro markets like Chicago, NY, and Los Angeles. The PAL spectrum cost in those markets is estimated to range around $0.30 per MHz-Pop. In top 400 or so counties where the majority of the population reside, the PAL spectrum cost is estimated at least $0.06 per MHz-Pop. In very rural counties, the cost can go down to $0.003 per MHz-Pop.

Based on relatively low-cost estimates of PAL licenses as outlined in this paper, Mobile Experts believes that multi-faceted use cases envisioned by the CBRS ecosystem can be realized. In other words, the CBRS spectrum cost won't likely be a long pole in the realization of commercial services using the 3.5 GHz CBRS bands.

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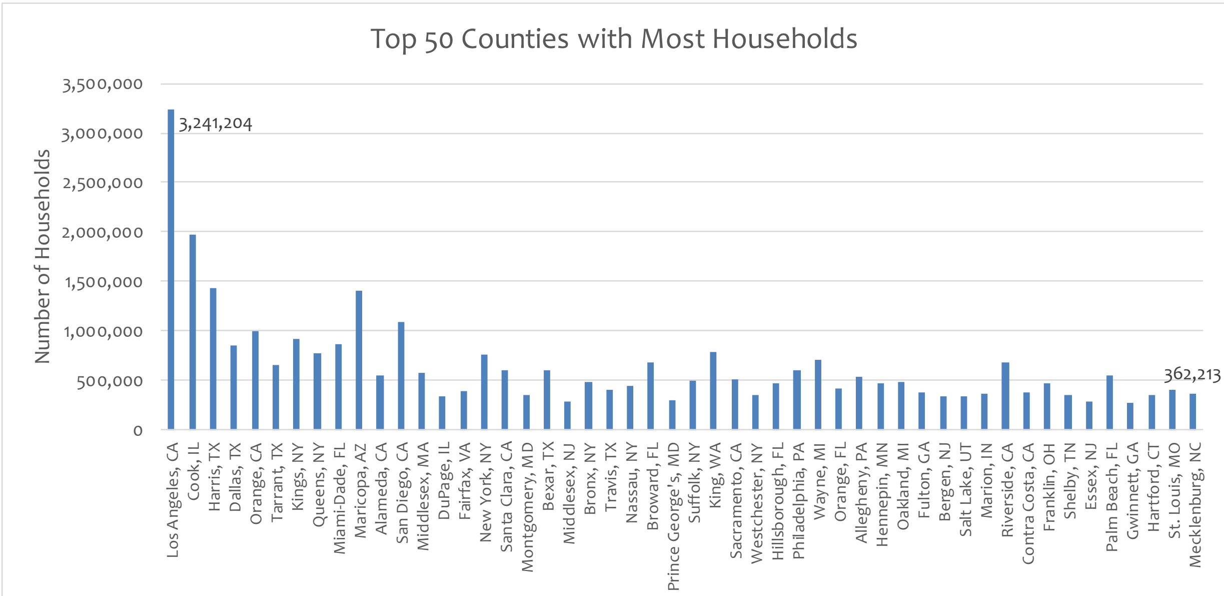
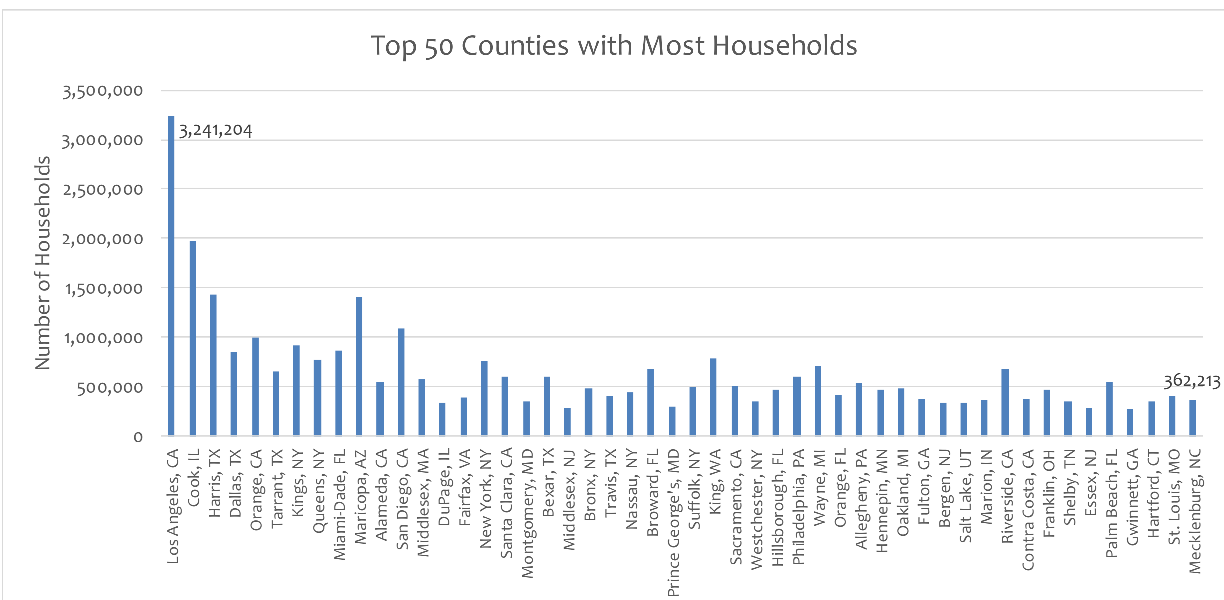
Appendix A: Top 50 U.S. Counties by Population



Appendix B: Top 50 U.S. Counties by Population Density



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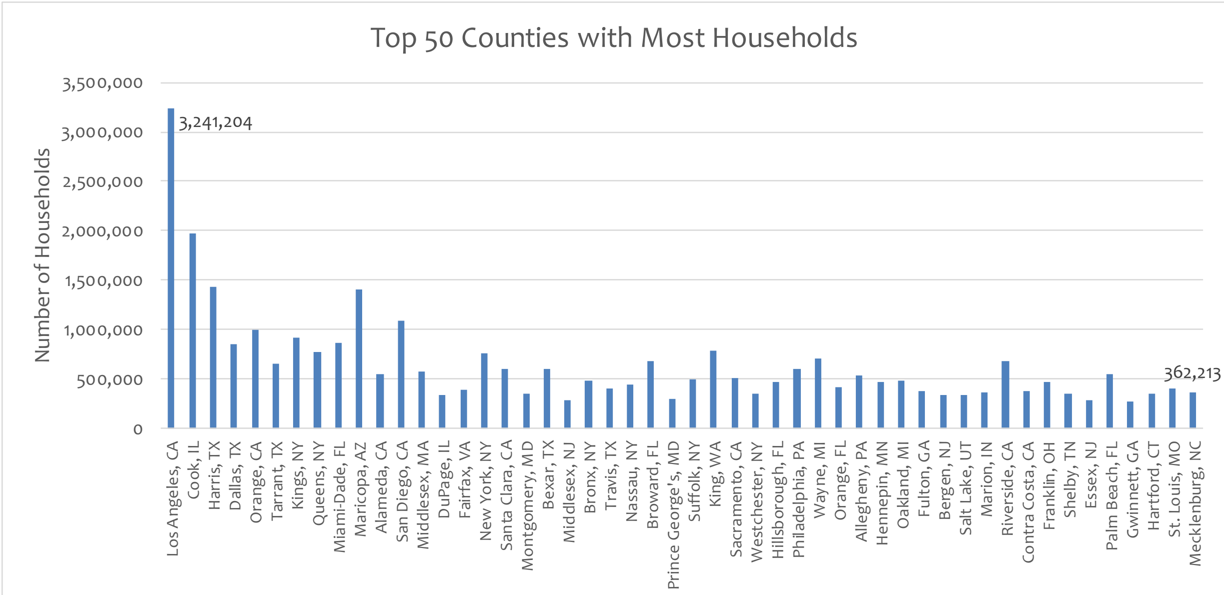
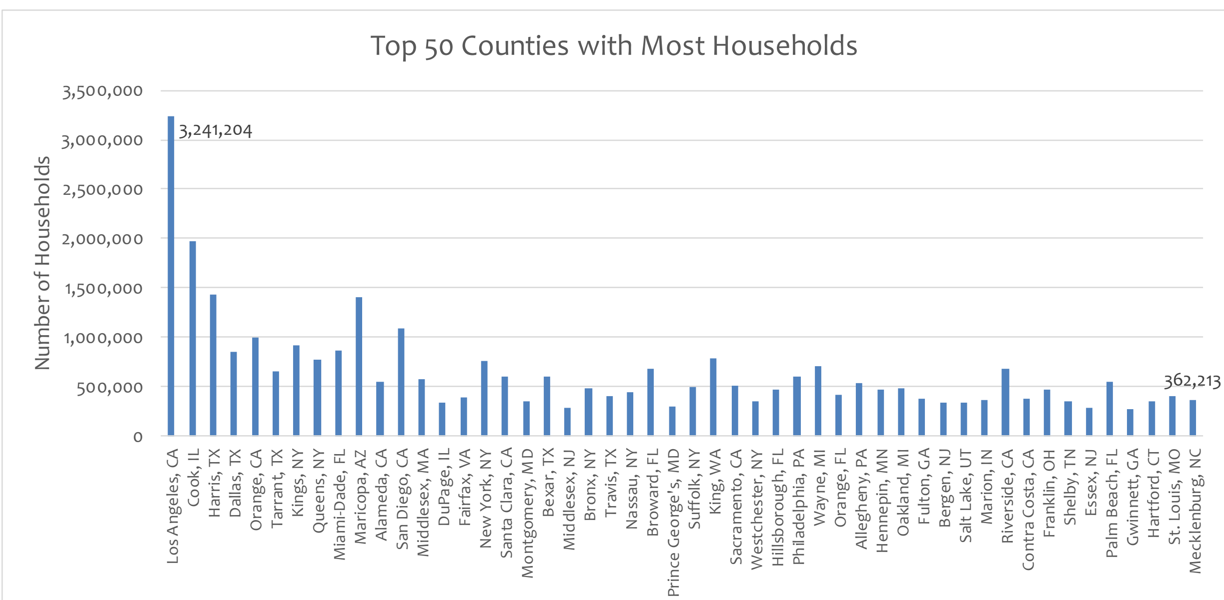
Appendix C: Top 50 U.S. Counties by Number of Households



Appendix D: Top 50 U.S. Counties by Housing Density



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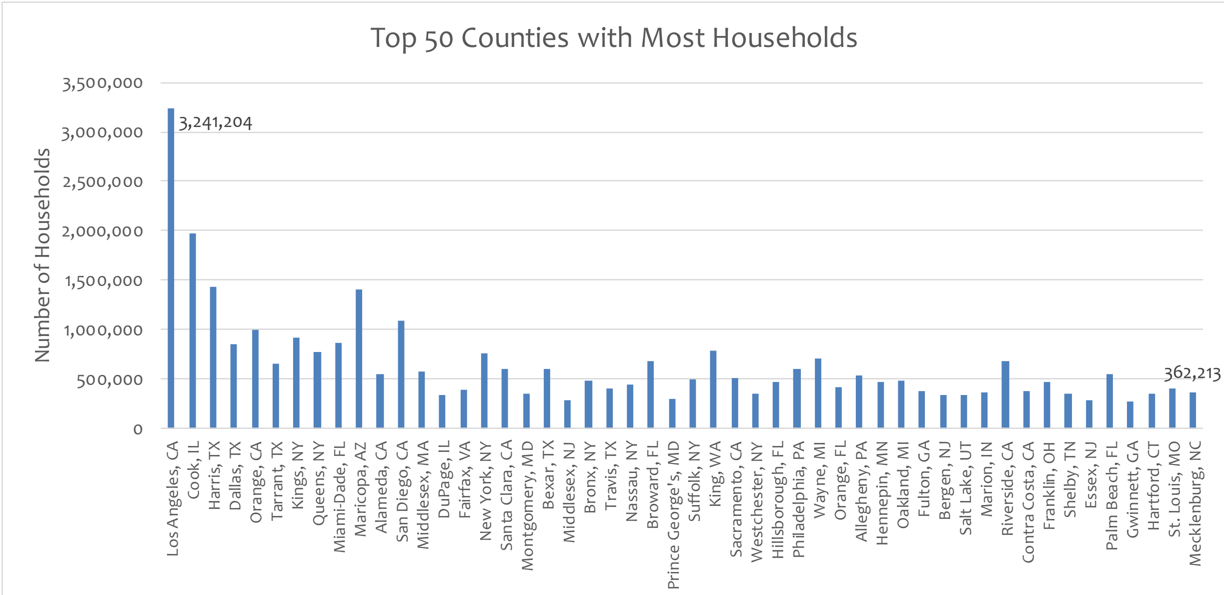
Appendix E: Top 50 U.S. Counties by Private Non-Farm Establishments



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Appendix F: Top 200 counties by estimated total PAL proceeds (seven 10MHz channels)

	Area_name	Population 2010	Private Non-farm Establishmen	Households 2010	Net $/MHZ-PoP	Total PAL Proceeds
1	Los Angeles, CA	9,818,605	227,941	3,241,204	$ 0.299	$ 205,503,403
2	Cook, IL	5,194,675	127,162	1,966,356	$ 0.325	$ 67,530,775
3	Maricopa, AZ	3,817,117	73,102	1,411,583	$ 0.250	$ 66,692,668
4	Harris, TX	4,092,459	85,205	1,435,155	$ 0.221	$ 63,310,341
5	San Diego, CA	3,095,313	69,059	1,086,865	$ 0.265	$ 57,461,391
6	Miami-Dade, FL	2,496,435	67,703	867,352	$ 0.257	$ 44,980,766
7	Riverside, CA	2,189,641	27,233	686,260	$ 0.286	$ 43,836,613
8	Dallas, TX	2,368,139	63,613	855,960	$ 0.254	$ 42,022,627
9	Santa Clara, CA	1,781,642	45,265	604,204	$ 0.296	$ 36,965,508
10	Orange, CA	3,010,232	79,937	992,781	$ 0.299	$ 36,002,375
11	King, WA	1,931,249	59,548	789,232	$ 0.242	$ 32,688,321
12	Tarrant, TX	1,809,034	33,748	657,134	$ 0.254	$ 32,101,308
13	Bexar, TX	1,714,773	29,726	608,931	$ 0.265	$ 31,833,046
14	San Bernardino, CA	2,035,210	27,352	611,618	$ 0.221	$ 31,484,699
15	Kings, NY	2,504,700	38,732	916,856	$ 0.299	$ 29,956,212
16	Broward, FL	1,748,066	51,036	686,047	$ 0.221	$ 27,042,581
17	Queens, NY	2,230,722	36,976	780,117	$ 0.299	$ 26,679,435
18	Alameda, CA	1,510,271	36,468	545,138	$ 0.208	$ 21,989,546
19	Orange, FL	1,145,956	26,607	421,847	$ 0.273	$ 21,899,219
20	Middlesex, MA	1,503,085	43,079	580,688	$ 0.208	$ 21,884,918
21	DuPage, IL	916,924	32,543	337,132	$ 0.325	$ 20,860,021
22	Fairfax, VA	1,081,726	25,811	391,627	$ 0.260	$ 19,687,413
23	New York, NY	1,585,873	106,493	763,846	$ 0.299	$ 18,967,041
24	Hillsborough, FL	1,229,226	27,430	474,030	$ 0.211	$ 18,121,250
25	Clark, NV	1,951,269	30,365	715,365	$ 0.130	$ 17,756,548
26	Montgomery, MD	971,777	25,967	357,086	$ 0.260	$ 17,686,341
27	Travis, TX	1,024,266	23,785	404,467	$ 0.242	$ 17,336,726
28	Middlesex, NJ	809,858	20,698	281,186	$ 0.299	$ 16,950,328
29	Bronx, NY	1,385,108	14,209	483,449	$ 0.299	$ 16,565,892
30	Nassau, NY	1,339,532	47,591	448,528	$ 0.299	$ 16,020,803
31	Salt Lake, UT	1,029,655	26,175	342,622	$ 0.218	$ 15,741,366
32	Prince George's, MD	863,420	13,960	304,042	$ 0.260	$ 15,714,244
33	Suffolk, NY	1,493,350	43,840	499,922	$ 0.150	$ 15,627,908
34	Sacramento, CA	1,418,788	25,909	513,945	$ 0.156	$ 15,493,165
35	Oakland, MI	1,202,362	42,013	483,698	$ 0.182	$ 15,318,092
36	Westchester, NY	949,113	30,809	347,232	$ 0.202	$ 13,387,239
37	Philadelphia, PA	1,526,006	25,621	599,736	$ 0.202	$ 12,299,608
38	Wayne, MI	1,820,584	35,887	702,749	$ 0.163	$ 11,833,796
39	Allegheny, PA	1,223,348	34,819	533,960	$ 0.130	$ 11,132,467
40	Hennepin, MN	1,152,425	39,022	475,913	$ 0.137	$ 11,011,421
41	Fulton, GA	920,581	31,327	376,377	$ 0.169	$ 10,890,473
42	Bergen, NJ	905,116	33,205	335,730	$ 0.299	$ 10,825,187
43	Marion, IN	903,393	24,021	366,176	$ 0.163	$ 10,276,095
44	Shelby, TN	927,644	21,134	350,971	$ 0.156	$ 10,129,872
45	Palm Beach, FL	1,320,134	37,392	544,227	$ 0.109	$ 10,091,104
46	Hartford, CT	894,014	23,001	350,854	$ 0.156	$ 9,762,633
47	Contra Costa, CA	1,049,025	22,285	375,364	$ 0.130	$ 9,546,128
48	Franklin, OH	1,163,414	28,098	477,235	$ 0.117	$ 9,528,361
49	Essex, NJ	783,969	19,748	283,712	$ 0.299	$ 9,376,269
50	Gwinnett, GA	805,321	18,360	268,519	$ 0.163	$ 9,160,526

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51	Wake, NC	900,993	20,812	345,645	**$ 0.140**	$ 8,854,959
52	St. Louis, MO	998,954	30,086	404,765	**$ 0.124**	$ 8,635,957
53	Duval, FL	864,263	21,341	342,450	**$ 0.140**	$ 8,493,977
54	Mecklenburg, NC	919,628	24,341	362,213	**$ 0.130**	$ 8,368,615
55	Fairfield, CT	916,829	28,673	335,545	**$ 0.130**	$ 8,343,144
56	Erie, NY	919,040	22,593	383,164	**$ 0.125**	$ 8,028,733
57	DeKalb, GA	691,893	16,941	271,809	**$ 0.163**	$ 7,870,283
58	New Haven, CT	862,477	20,549	334,502	**$ 0.130**	$ 7,848,541
59	Cobb, GA	688,078	18,024	260,056	**$ 0.163**	$ 7,826,887
60	Macomb, MI	840,978	18,739	331,667	**$ 0.130**	$ 7,652,900
61	Hudson, NJ	634,266	13,471	246,437	**$ 0.299**	$ 7,585,821
62	San Francisco, CA	805,235	30,643	345,811	**$ 0.228**	$ 7,327,639
63	Baltimore, MD	805,029	18,877	316,715	**$ 0.130**	$ 7,325,764
64	Monroe, NY	744,344	16,828	300,422	**$ 0.140**	$ 7,315,413
65	Montgomery, PA	799,874	26,051	307,750	**$ 0.130**	$ 7,278,853
66	Camden, NJ	513,657	12,528	190,980	**$ 0.202**	$ 7,245,132
67	Oklahoma, OK	718,633	21,258	287,598	**$ 0.140**	$ 7,062,725
68	Cuyahoga, OH	1,280,122	37,897	545,056	**$ 0.078**	$ 6,989,466
69	Monmouth, NJ	630,380	18,699	233,983	**$ 0.156**	$ 6,883,750
70	Collin, TX	782,341	11,855	283,759	**$ 0.125**	$ 6,834,531
71	Essex, MA	743,159	18,634	285,956	**$ 0.130**	$ 6,762,747
72	Multnomah, OR	735,334	23,593	304,540	**$ 0.130**	$ 6,691,539
73	Jackson, MO	674,158	17,659	274,804	**$ 0.140**	$ 6,625,625
74	San Mateo, CA	718,451	20,378	257,837	**$ 0.130**	$ 6,537,904
75	Baltimore city, MD	620,961	13,583	249,903	**$ 0.260**	$ 6,457,994
76	Union, NJ	536,499	14,709	188,118	**$ 0.299**	$ 6,416,528
77	Lake, IL	703,462	18,388	241,712	**$ 0.130**	$ 6,401,504
78	District of Columbia	601,723	19,686	266,707	**$ 0.260**	$ 6,257,919
79	Pinellas, FL	916,542	25,825	415,876	**$ 0.169**	$ 6,195,824
80	Bucks, PA	625,249	18,032	234,849	**$ 0.140**	$ 6,144,947
81	El Paso, TX	800,647	12,214	256,557	**$ 0.109**	$ 6,120,146
82	Norfolk, MA	670,850	19,738	257,914	**$ 0.130**	$ 6,104,735
83	Suffolk, MA	722,023	20,395	292,767	**$ 0.208**	$ 6,007,231
84	Tulsa, OK	603,403	18,260	241,737	**$ 0.140**	$ 5,930,245
85	Will, IL	677,560	10,373	225,256	**$ 0.125**	$ 5,919,164
86	New Castle, DE	538,479	16,386	202,651	**$ 0.156**	$ 5,880,191
87	Anne Arundel, MD	537,656	12,281	199,378	**$ 0.156**	$ 5,871,204
88	Davidson, TN	626,681	18,155	259,499	**$ 0.130**	$ 5,702,797
89	Providence, RI	626,667	16,213	241,717	**$ 0.130**	$ 5,702,670
90	Honolulu, HI	953,207	20,801	311,047	**$ 0.085**	$ 5,638,219
91	Milwaukee, WI	947,735	21,210	383,591	**$ 0.143**	$ 5,421,044
92	Ventura, CA	823,318	17,510	266,920	**$ 0.094**	$ 5,394,380
93	Johnson, KS	544,179	15,938	212,882	**$ 0.140**	$ 5,348,191
94	Montgomery, OH	535,153	13,084	223,943	**$ 0.140**	$ 5,259,484
95	Worcester, MA	798,552	18,129	303,080	**$ 0.094**	$ 5,232,113
96	Pierce, WA	795,225	15,573	299,918	**$ 0.094**	$ 5,210,314
97	Denver, CO	600,158	22,175	263,107	**$ 0.215**	$ 5,149,356
98	Hamilton, OH	802,374	24,703	333,945	**$ 0.091**	$ 5,111,122
99	Ocean, NJ	576,567	11,226	221,111	**$ 0.125**	$ 5,036,889
100	Summit, OH	541,781	14,476	222,781	**$ 0.130**	$ 4,930,207

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101	Morris, NJ	492,276	17,575	180,534	**$ 0.140**	$ 4,838,089
102	Bristol, MA	548,285	13,364	213,010	**$ 0.125**	$ 4,789,818
103	Lee, FL	618,754	12,785	259,818	**$ 0.109**	$ 4,729,756
104	Jefferson, KY	741,096	19,774	309,175	**$ 0.091**	$ 4,720,782
105	Douglas, NE	517,110	14,151	202,411	**$ 0.130**	$ 4,705,701
106	Kent, MI	602,622	15,428	227,239	**$ 0.109**	$ 4,606,443
107	Kane, IL	515,269	10,499	170,479	**$ 0.125**	$ 4,501,390
108	San Joaquin, CA	685,306	10,350	215,007	**$ 0.094**	$ 4,490,125
109	Richmond, NY	468,730	7,506	165,516	**$ 0.239**	$ 4,484,809
110	Arapahoe, CO	572,003	16,645	224,011	**$ 0.109**	$ 4,372,391
111	Delaware, PA	558,979	13,214	208,700	**$ 0.195**	$ 4,360,036
112	Bernalillo, NM	662,564	15,576	266,000	**$ 0.094**	$ 4,341,119
113	Jefferson, AL	658,466	17,397	263,568	**$ 0.094**	$ 4,314,269
114	Hidalgo, TX	774,769	8,382	216,471	**$ 0.078**	$ 4,230,239
115	Denton, TX	662,614	8,277	240,289	**$ 0.091**	$ 4,220,851
116	Jefferson, CO	534,543	16,202	218,160	**$ 0.109**	$ 4,086,047
117	Washington, OR	529,710	12,512	200,934	**$ 0.109**	$ 4,049,103
118	Lucas, OH	441,815	11,082	180,267	**$ 0.130**	$ 4,020,517
119	Virginia Beach, VA	437,994	10,188	165,089	**$ 0.130**	$ 3,985,745
120	Jefferson, LA	432,552	12,694	169,647	**$ 0.130**	$ 3,936,223
121	Snohomish, WA	713,335	15,355	268,325	**$ 0.078**	$ 3,894,809
122	Seminole, FL	422,718	10,725	164,706	**$ 0.130**	$ 3,846,734
123	East Baton Rouge, LA	440,171	11,415	172,057	**$ 0.125**	$ 3,845,334
124	Chester, PA	498,886	12,399	182,900	**$ 0.109**	$ 3,813,485
125	Plymouth, MA	494,919	11,977	181,126	**$ 0.109**	$ 3,783,161
126	Knox, TN	432,226	11,099	177,249	**$ 0.125**	$ 3,775,926
127	Guilford, NC	488,406	13,615	196,628	**$ 0.109**	$ 3,733,375
128	Fort Bend, TX	585,375	6,291	187,384	**$ 0.091**	$ 3,728,839
129	Lake, IN	496,005	9,952	188,157	**$ 0.104**	$ 3,610,916
130	Onondaga, NY	467,026	11,737	187,686	**$ 0.109**	$ 3,569,947
131	Brevard, FL	543,376	11,484	229,692	**$ 0.094**	$ 3,560,200
132	Hampden, MA	463,490	11,992	179,927	**$ 0.109**	$ 3,542,918
133	Rockland, NY	311,687	8,660	99,242	**$ 0.156**	$ 3,403,622
134	Lancaster, PA	519,445	11,524	193,602	**$ 0.094**	$ 3,403,404
135	Mercer, NJ	366,513	10,088	133,155	**$ 0.130**	$ 3,335,268
136	Prince William, VA	402,002	4,447	130,785	**$ 0.117**	$ 3,292,396
137	Polk, IA	430,640	11,577	170,197	**$ 0.109**	$ 3,291,812
138	Sedgwick, KS	498,365	11,911	193,502	**$ 0.094**	$ 3,265,287
139	Volusia, FL	494,593	10,827	208,236	**$ 0.094**	$ 3,240,573
140	Dane, WI	488,073	12,537	203,750	**$ 0.094**	$ 3,197,854
141	Waukesha, WI	389,891	12,526	152,663	**$ 0.109**	$ 2,980,327
142	Pasco, FL	464,697	6,289	189,612	**$ 0.091**	$ 2,960,120
143	Greenville, SC	451,225	11,468	176,531	**$ 0.094**	$ 2,956,426
144	Burlington, NJ	448,734	10,411	166,318	**$ 0.094**	$ 2,940,105
145	Sarasota, FL	379,448	11,493	175,746	**$ 0.109**	$ 2,900,501
146	Lehigh, PA	349,497	8,190	133,983	**$ 0.117**	$ 2,862,380
147	Clayton, GA	259,424	4,340	90,633	**$ 0.156**	$ 2,832,910
148	Ramsey, MN	508,640	13,836	202,691	**$ 0.137**	$ 2,777,174
149	Polk, FL	602,095	9,606	227,485	**$ 0.065**	$ 2,739,532
150	Genesee, MI	425,790	9,087	169,202	**$ 0.091**	$ 2,712,282

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151	Clark, WA	425,363	8,163	158,099	**$ 0.091**	$ 2,709,562
152	Pima, AZ	980,263	18,828	388,660	**$ 0.039**	$ 2,676,118
153	Somerset, NJ	323,444	9,545	117,759	**$ 0.117**	$ 2,649,006
154	Sonoma, CA	483,878	13,526	185,825	**$ 0.078**	$ 2,641,974
155	Hillsborough, NH	400,721	10,781	155,466	**$ 0.094**	$ 2,625,524
156	Forsyth, NC	350,670	8,493	141,163	**$ 0.104**	$ 2,552,878
157	Dakota, MN	398,552	9,021	152,060	**$ 0.091**	$ 2,538,776
158	Davis, UT	306,479	4,728	93,545	**$ 0.117**	$ 2,510,063
159	Passaic, NJ	501,226	11,843	166,785	**$ 0.072**	$ 2,508,636
160	Pulaski, AR	382,748	11,671	158,772	**$ 0.094**	$ 2,507,765
161	Montgomery, TX	455,746	5,995	162,530	**$ 0.078**	$ 2,488,373
162	Fayette, KY	295,803	7,869	123,043	**$ 0.117**	$ 2,422,627
163	Stark, OH	375,586	9,413	151,089	**$ 0.091**	$ 2,392,483
164	York, PA	434,972	8,234	168,372	**$ 0.078**	$ 2,374,947
165	Howard, MD	287,085	7,373	104,749	**$ 0.117**	$ 2,351,226
166	Orleans, LA	343,829	10,628	142,158	**$ 0.098**	$ 2,346,633
167	Butler, OH	368,130	6,220	135,960	**$ 0.091**	$ 2,344,988
168	Stanislaus, CA	514,453	8,298	165,180	**$ 0.065**	$ 2,340,761
169	St. Charles, MO	360,485	6,321	134,274	**$ 0.091**	$ 2,296,289
170	Solano, CA	413,344	6,584	141,758	**$ 0.078**	$ 2,256,858
171	Berks, PA	411,442	8,210	154,356	**$ 0.078**	$ 2,246,473
172	Henrico, VA	306,935	7,367	124,601	**$ 0.104**	$ 2,234,487
173	Cameron, TX	406,220	5,847	119,631	**$ 0.078**	$ 2,217,961
174	Northampton, PA	297,735	5,667	113,565	**$ 0.104**	$ 2,167,511
175	Hamilton, TN	336,463	8,810	136,682	**$ 0.091**	$ 2,143,269
176	Ada, ID	392,365	10,275	148,445	**$ 0.078**	$ 2,142,313
177	Anoka, MN	330,844	6,786	121,227	**$ 0.091**	$ 2,107,476
178	Richland, SC	384,504	9,265	145,194	**$ 0.078**	$ 2,099,392
179	Gloucester, NJ	288,288	5,742	104,271	**$ 0.104**	$ 2,098,737
180	Orange, NY	372,813	8,220	125,925	**$ 0.078**	$ 2,035,559
181	Norfolk, VA	242,803	5,437	86,485	**$ 0.208**	$ 2,020,121
182	Chesterfield, VA	316,236	5,558	115,680	**$ 0.091**	$ 2,014,423
183	Adams, CO	441,603	7,245	153,764	**$ 0.065**	$ 2,009,294
184	Loudoun, VA	312,311	4,724	104,583	**$ 0.091**	$ 1,989,421
185	Durham, NC	267,587	5,964	109,348	**$ 0.104**	$ 1,948,033
186	Allen, IN	355,329	8,984	137,851	**$ 0.078**	$ 1,940,096
187	Boulder, CO	294,567	11,361	119,300	**$ 0.094**	$ 1,930,003
188	Williamson, TX	422,679	5,024	152,606	**$ 0.065**	$ 1,923,189
189	Lorain, OH	301,356	5,873	116,274	**$ 0.091**	$ 1,919,638
190	Charleston, SC	350,209	10,520	144,309	**$ 0.078**	$ 1,912,141
191	Lake, OH	230,041	6,417	94,156	**$ 0.117**	$ 1,884,036
192	Washtenaw, MI	344,791	8,270	137,193	**$ 0.078**	$ 1,882,559
193	Mobile, AL	412,992	9,227	158,435	**$ 0.065**	$ 1,879,114
194	Nueces, TX	340,223	7,849	124,587	**$ 0.078**	$ 1,857,618
195	Galveston, TX	291,309	4,808	108,969	**$ 0.091**	$ 1,855,638
196	Madison, AL	334,811	7,175	134,700	**$ 0.078**	$ 1,828,068
197	Manatee, FL	322,833	5,711	135,729	**$ 0.078**	$ 1,762,668
198	Hamilton, IN	274,569	5,503	99,835	**$ 0.091**	$ 1,749,005
199	Cumberland, NC	319,431	5,250	122,431	**$ 0.078**	$ 1,744,093
200	Arlington, VA	207,627	5,233	98,050	**$ 0.208**	$ 1,727,457

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